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AN ELECTRONIC ANALYSIS OF SOME  
SURFACES BY MEANS OF SLOW  
ELECTRONS

A DISSERTATION SUBMITTED TO THE  
FACULTY OF THE DIVISION OF THE  
PHYSICAL SCIENCES IN CANDIDACY FOR  
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF CHEMISTRY

1936

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By  
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# AN ELECTRONIC ANALYSIS OF SOME SURFACES BY MEANS OF SLOW ELECTRONS<sup>1</sup>

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## INTRODUCTION

Much of our knowledge of matter is that of its surface. It is fortunate that we have such information concerning surfaces, for many different types of physical and chemical phenomena are quite dependent upon the nature of the surface. For example, the absorption and emission of heat and light, thermionic emission, secondary electron and photoelectron emission, contact potentials, surface tension, rate of a chemical reaction, catalysis, adsorption, friction and so forth are dependent upon the condition of one or more surfaces. A surface may be thought of as consisting of atoms or molecules distributed at random, or in some orderly fashion. The interaction of waves with a regularly arranged network of matter produces reflected waves, which combine in such a way that, from their space intensity distribution recorded at a distance from the network, some dimensions of the network may be calculated. Electron waves are now a reality and have become a useful tool in studying atomic and molecular networks found at and near the surface.

Since the discovery of the wave characteristics of electron beams by Davisson and Germer (2) many workers have used electron waves to investigate films and surfaces of crystalline solids. Some organic liquids have been studied (1, 3).

Slow electron waves have the least penetrating power of any radiation which exhibits a wave nature, therefore they are quite sensitive to surface layers. Low velocity electrons probably never penetrate more than ten atom layers. The major part of the diffraction of the electron wave by metals occurs in the first two layers.<sup>2</sup> Slow electrons are quite suitable for the study of surfaces which consist of only a few molecular layers.

<sup>1</sup> Reprinted from *The Journal of Physical Chemistry*, **40**, 941-957 (1936).

<sup>2</sup> "A known number of atom layers of one metal were deposited on the surface of a single crystal of another metal by evaporation in high vacuum. Direct results on depth of penetration were obtained from measurements on electron diffraction as a function of the thickness of the surface layer. A silver film deposited on a copper crystal is amorphous. A layer one atom deep reduces the maxima of the beams from

## THEORETICAL DISCUSSION

An electron beam incident on a surface makes an angle  $\theta$  with the surface. In order to measure distances normal to the surface by means of diffracting electron waves, the condition that the angle of incidence equal the angle of reflection must be satisfied, and this may be met by having the collector receive only those electrons reflected at an angle equal to the angle of incidence. If the surface is composed of atoms lying in planes spaced at a distance  $d$ , measured normal to the surface, and the Bragg condition

$$n\lambda = 2d \sin \theta \quad (1)$$

is satisfied, electron waves reinforce each other and a maximum collector current results. Here  $\lambda$  is the wave length of the electron wave as given by the de Broglie relation

$$\lambda = h/mv \text{ centimeters} \quad (2)$$

where  $h$  is Plank's constant,  $m$  is the mass of the electron, and  $v$  is the velocity of the electron. In turn,  $v$  is given by

$$v = (2Ve/m)^{\frac{1}{2}} \quad (3)$$

where  $V$  is the accelerating potential in absolute E.S.U., and  $e$  is the charge on the electron in absolute E.S.U. Substitution of this in equation 2 gives

$$\lambda = \frac{12.214 \times 10^{-8} \text{ cm.}}{(P)^{\frac{1}{2}}} \quad (4)$$

where  $P$  is the accelerating potential measured in practical volts. Substitution of equation 4 in equation 1 gives

$$P^{\frac{1}{2}} \sin \theta = 6.107 \times n/d \quad (5)$$

which is the condition that is satisfied for maximum collector current. This relation assumes no inner potential.

For a given surface having zero inner potential the condition for maximum collector current is  $P^{\frac{1}{2}} = \text{constant} \times n$ . If two maxima are chosen with quite a few others existing between, ordering of the maximum may be readily accomplished. For

$$P_1^{\frac{1}{2}}/P_2^{\frac{1}{2}} = n_1/n_2$$

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the copper lattice by at least seventy per cent for energies up to 300 electron volts. A number of foreign silver atoms equal to a few hundredths of that contained in one atomic layer can be detected by this method. A silver film deposited on a gold crystal is crystalline. The surface atomic layer of silver contributes at least ninety per cent. This predominating effect of surface atomic layers for primary energies as high as 300 electron volts is not in accord with the theoretical predictions of v. Laue." (Farnsworth, H. E.: Phys. Rev. **47**, 331A (1935).)



where  $P_1$  is the voltage where maximum of the order  $n_1$  occurs, and  $P_2$  is the voltage for maximum  $n_2$ . Now  $n_2 = n_1 + a$ , where  $a$  is the number of maxima existing in going from  $n_1$  to  $n_2$ . Substitution for  $n_2$  and rearranging gives

$$n_1 = a \frac{P_1^{\frac{1}{2}}}{P_2^{\frac{1}{2}}} - P_1^{\frac{1}{2}} \quad (6)$$

from which the order  $n_1$  may be found.

The more general cases of diffraction of electrons must take into account the so-called inner potential,  $\phi$ . The velocity of the electron wave within the lattice will be different from the velocity of the electron wave just outside the lattice, if the inner potential is different from zero. The ratio of these velocities, or in other words the index of refraction,  $\mu$ , is given by

$$\mu = \left(1 + \frac{\phi}{P}\right)^{\frac{1}{2}} \quad (7)$$

and the maxima should obey

$$P^{\frac{1}{2}} \sin \theta = 6.107 \frac{n}{d} \left(1 - \frac{4d^2\phi}{150n^2}\right)^{\frac{1}{2}} \quad (8)$$

#### APPARATUS

An electron diffraction apparatus (figure 1) was constructed which has the following features: (1) The specimen holder remains in a fixed plane. (2) The specimen holder may be quickly removed, and replaced when changing specimens. (3) The collector and electron gun can be simultaneously rotated in such a way as to satisfy the condition that the angle of incidence equal the angle of reflection. (4) The filament of the electron gun may be renewed through a side tube. (5) The entire apparatus is constructed of brass to avoid contact potentials.

The electron beam is produced by means of an electron gun (G), and is collimated by means of three thin circular apertures ( $S_1$ ,  $S_2$ ,  $S_3$ ) 0.55 mm. in diameter. The entire slit system is mounted upon arm  $A_1$ , and may be adjusted by the two screws (V) for alignment. The collar (W) holds the filament system in the correct position, and may be removed when spot-welding a renewal filament, which consists of three turns of 0.005-in. tungsten wire forming a spiral 1 mm. in diameter. It is spot-welded onto two 0.040-in. nickel wire leads. The axis of the spiral is coaxial with the slit system. The filament spiral is 1 mm. from the first aperture ( $S_1$ ). The nickel leads are supported by means of a lavite insulator. A copper strip  $\frac{5}{8}$  in. long,  $\frac{1}{16}$  in. wide, and  $\frac{1}{32}$  in. thick, bent in the middle to form a split connector, is silver-soldered to each end of the nickel wire leads, and these connectors are held by means of two lavite blocks, the upper one of

which has a brass screw (L) attached to it which passes through the hexagonal nut held by means of a shoulder in the brass case. Pressure is applied on the copper contacts when the nut is turned in a counter-clockwise direction, so that the two brass tips may be clamped in the copper connectors. These brass tips are mounted in a lavite block, which is supported on the shield K, which has a bearing in the center of the shaft connected to the electron gun arm and carries two flexible copper conductors, which consist of seventy-two strands of 0.005-in. wire, insulated from the shield by means of glass beads. The upper conductors are silver-soldered to the brass tips. The shield has a small rack attached to it

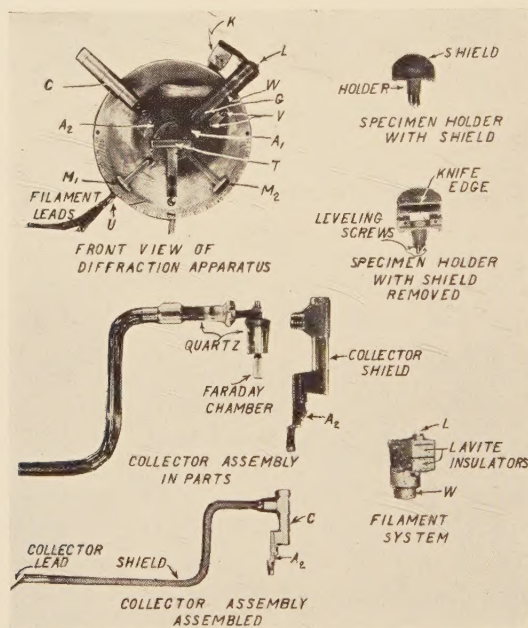


FIG. 1. Electron diffraction apparatus

which enables the brass tips to be slipped from between the copper connectors by means of a tool containing a small pinion gear, which centers on the brass nut. The filament assembly can be removed through a side tube when the brass tips are in this position. A small spring catch either holds the brass tips in between the connectors, or holds them away. The copper tubes (U) shield the filament leads up to the point at which they leave the glass enclosure. Shielding outside the enclosure is effected by means of a braided copper sheath.

The collector (C) consisted of a small Faraday chamber held in place by a quartz insulator behind the 0.55-mm. aperture, which is mounted on the



arm ( $A_2$ ). The lead to the collector is brought through a quartz tube (6 mm. outside diameter, 3 mm. inside diameter), and it is bent so that the electrometer lead leaves the quartz insulator coaxial with the mechanism used to rotate the collector and gun. A braided copper shield over the

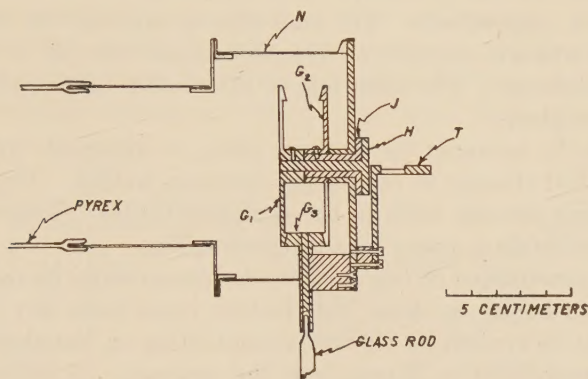


FIG. 2. Gearing mechanism

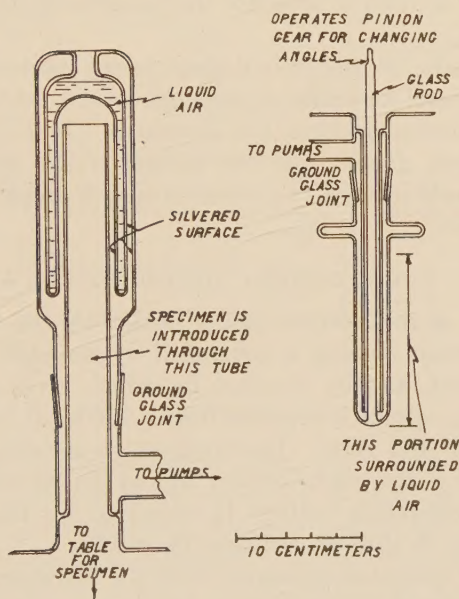


FIG. 3. Grease traps

quartz serves for electrostatic shielding for the electrometer lead within the glass enclosure.

The arm of the electron gun is fastened rigidly to the shaft H (figure 2), which is, in turn, fastened rigidly to the gear G. The collector arm is fastened rigidly to the shaft J, which is fastened to the gear  $G_2$  by means of three

set screws. Motion in opposite directions is imparted to the gears  $G_1$ ,  $G_2$  by the small gear  $G_3$ . The three set screws on the large gear ( $G_1$ ) allow adjustment of the collector, so that the angle of incidence equals the angle of reflection. The angles are read from the scale engraved on the base plate by the two indexes ( $M_1$ ,  $M_2$ ) connected to the electron gun and collector, respectively. The base plate is mounted on the large copper tube N, which is mounted on a smaller copper tube ( $2\frac{1}{2}$  in. in diameter) by a slotted flange. The other end of the smaller tube is sealed directly to the Pyrex glass.

The table T, mounted on the base plate, is adjustable for alignment. It has a milled channel to receive the specimen holder. The specimen is mounted on a circular table in the specimen holder. This table is held against three leveling screws by a tungsten spring.

A shield constructed of two semicircular pieces could be mounted upon the specimen holder to shield the electron beam from any electric field which might be created by charges accumulating on the glass wall of the enclosure approximately 76 mm. from the specimen. A  $10^\circ$  wedge placed between the two semicircular pieces with its knife edge 0.5 mm. from the specimen could be used to separate the incident electron beam from the diffracted beam.

It was necessary to use ground glass joints lubricated with stopcock grease on the control for changing the angle and on the tube through which the specimen is introduced into the apparatus. It is equally necessary to keep the stopcock grease from the surface of the specimen. Figure 3 illustrates the method used to prevent stopcock grease from entering the apparatus proper.

#### THE ELECTRICAL CIRCUIT (FIGURE 4)

The filament of the electron gun is heated by the battery ( $B_f$ , figure 4) and the filament heating is controlled by rheostat  $R_1$ , which gives a coarse adjustment, and by rheostat  $R_2$ , which gives a fine adjustment. The accelerating voltage is supplied from a 1000-volt lead storage battery ( $B_{A1}$ ) in steps of 100 volts. Intermediate accelerating voltages are obtained by means of the potentiometer  $R_4$  and the 50-volt auxiliary battery ( $B_{A2}$ ). The accelerating voltage is measured by the potentiometer P and the volt-box  $R_3$  through switches  $Q_2$  and  $Q_3$ .

The collector current is measured with the Dershem electrometer (E). The electrometer leak ( $R_5$ ) of  $2.56 \times 10^{11}$  ohms was not used in all of the experiments. The electrometer sensitivity control employed the following resistances:  $R_5 = 80,000$  ohms;  $R_6 = 2,000$  ohms;  $R_7 = 80,000$  ohms; and  $R_8$ , which consisted of two variable resistances of 50,000 ohms and 1,000 ohms connected in series. The electrometer sensitivity was checked



throughout an experiment by the potentiometer P, through the grounding key Q<sub>1</sub> and the switches Q<sub>2</sub> and Q<sub>4</sub>.

In some of the experiments a constant retarding potential was applied to the collector by introducing a battery between points a and b. In later experiments apertures  $S_4$  and  $S_5$ , 1 mm. in diameter, were added to the collector, and  $S_6$  was enlarged to 1 mm. in diameter. The retarding potential was then applied between the aperture  $S_4$  and  $S_5$  and was equal to the accelerating potential minus the potential from battery  $B_R$ . If vacuum conditions were poor, positive ions would form around  $S_5$ , com-

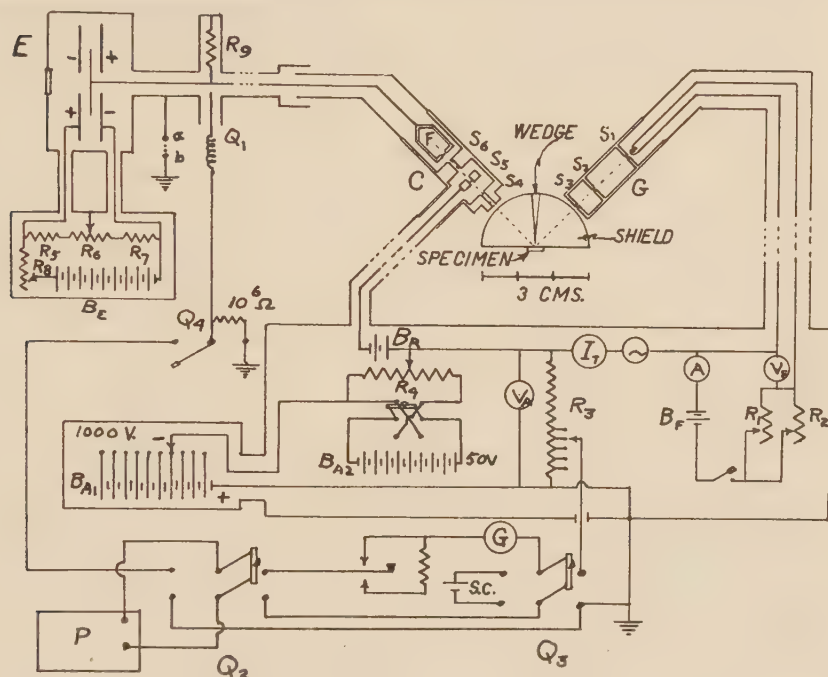


FIG. 4. Electrical circuit

pletely shielding it from the electron beam, and in order to stop electrons from entering the collector, it was necessary to make  $S_5$  several volts (35 volts in some cases) more negative than the electron gun filament.

All parts of the diffraction apparatus, with the exception of the electron gun filament, aperture S<sub>5</sub>, and the Faraday chamber, were at ground potential.

## MEASUREMENTS

### Diffraction of electrons from oleic acid

Some of Kahlbaum's technical oleic acid, which had been further purified by evaporation in a vacuum at an extremely slow rate, was first investi-

gated. The drift-rate method<sup>3</sup> was used to measure the collector current. The filament heating current was kept constant, and the thermionic emission was read for each accelerating voltage. The electron beam was interrupted between measurements.

*Experiment with a fixed angle of  $7^{\circ}30'$ .* The values of  $i_c/i_t$  (collector current/thermionic current) in arbitrary units are plotted as the ordinate, and values of  $P_a^{\frac{1}{2}}$  (square root of accelerating voltage) in units of (practical volts) <sup>$\frac{1}{2}$</sup>  are plotted as the abscissa in figure 5. Data for the curve follows a sequence in voltage from *A* to *B*, then *C* to *D*, and then *E* to *F*. The data form a smooth curve from *A* to *B*. Curves *CD* and *EF* are displaced, owing to the large jumps in voltage from *BC* and *D* to *E*. It is noted that

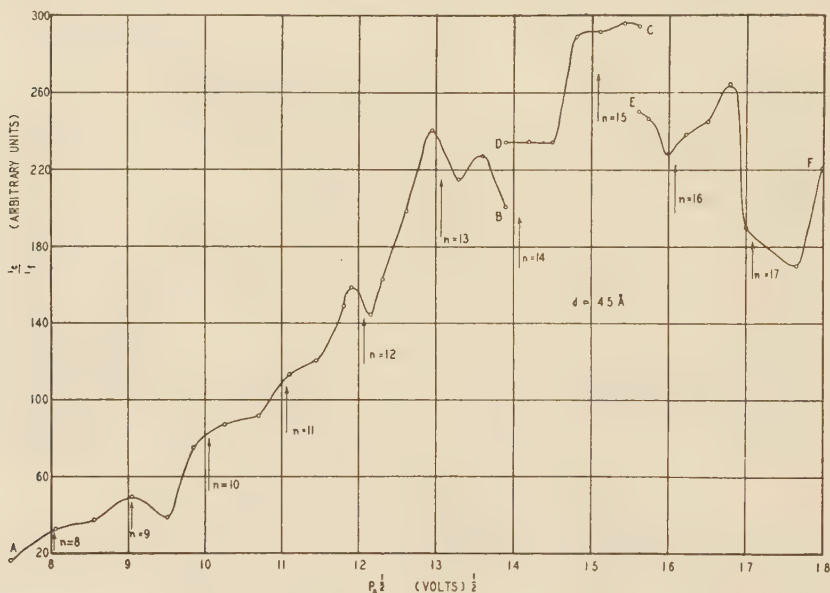


FIG. 5. Diffraction of electrons from oleic acid.  $\theta = 7^{\circ}30'$

the change in intensity ( $i_c/i_t$ ) is greater for the jump *B* to *C* than for the jump *D* to *E*. Many workers<sup>4</sup> in electron diffraction have found reduction in intensity with continued bombardment with electrons, and have classified it as a "fatigue effect," possibly due to a growing surface charge. The effect above, however, is found when a large change in voltage is made, and might be classed as a fatigue effect in view of the fact that, if a period of half an hour is allowed to elapse, the erratic points return to normal values.

<sup>3</sup> The time required for drifting between two fixed points 20 mm. apart on the electrometer scale was measured. The current is inversely proportional to this time. The electrometer sensitivity was 500 mm. per volt.

<sup>4</sup> G. P. Thomson, Emslie, Rupp, Dames, and others.



In ordering the maxima it was assumed that the maxima in the curve from  $A$  to  $B$  belonged to the same spacing distance, and that the inner potential was zero. A maximum exists at  $P_1^{\frac{1}{2}} = 8.03$  volts<sup>1</sup>, and another at  $P_2^{\frac{1}{2}} = 13.1$  volts<sup>1</sup>. There are five maxima ( $a = 5$ ) in going from  $n_1$  to  $n_2$ . Substitution in equation 6 gives  $n_1 =$  approximately 8, as  $n$  must be a whole number. Substitution of these orders in the Bragg equation gives

$$d = 44.9 \text{ A.U.}$$

Table 1 gives the various values of  $P^{\frac{1}{2}}$  as calculated for  $d = 44.9$  A.U. and the observed values of  $P^{\frac{1}{2}}$ .

The arrows in figure 5 indicate the positions of the calculated maxima. The calculated positions for the fourteenth and sixteenth orders are misfits.

TABLE 1  
*Calculated and observed values of  $P^{\frac{1}{2}}$*

| ORDER | $P^{\frac{1}{2}}$<br>(CALCULATED) | $P^{\frac{1}{2}}$<br>(OBSERVED) |
|-------|-----------------------------------|---------------------------------|
| 8     | 8.03                              | $8.03 \pm 0.05$                 |
| 9     | 9.04                              | 9.05                            |
| 10    | 10.04                             | 10.05                           |
| 11    | 11.05                             | 11.05                           |
| 12    | 12.05                             | 11.95                           |
| 13    | 13.06                             | 12.95                           |
| 14    | 14.07                             | 13.6                            |
| 15    | 15.08                             | Insufficient data               |
| 16    | 16.08                             | 16.0 (minima)                   |
| 17    | 17.09                             | 16.8                            |
| 18    | 18.09                             | Insufficient data               |

*Experiments with a fixed angle of  $30^\circ$ .* These data exhibit three rather broad maxima (figure 6). The best fit for these maxima corresponds to a spacing distance of 3.2 A.U. for the second, third, and fourth orders. This distance is considerably less than the 4.8 A.U. for oleic acid, which was found by Sogani (5) by diffraction of x-rays. However, Sogani's values are, for the most part, large. There are several minor peaks on the broad ones, which are outside of the experimental error. These might be assigned to the very large spacing found in the previous experiment. For a spacing of 45 A.U.,  $\Delta P^{\frac{1}{2}}$  should have a value of 0.271 volts<sup>1</sup>. On examining the curve, several peaks are found which might belong to this spacing. However, for  $P_a^{\frac{1}{2}} = 10$ , the order is 43 and the intensity of these peaks is expected to be extremely weak.

The values on the curve were taken in the following order: from  $a$  to  $b$ ; then the single point  $c$ ; then  $d$  to  $e$ . Point  $c$  is far below the curve. The curve  $d$  to  $e$  was affected very little, if any, by the jump to point  $c$ , as only

a single reading was taken there and it required a bombarding time of sixty-five seconds. This would seem to indicate that the charging up of the surface (if that is the case) requires a greater time than one minute.

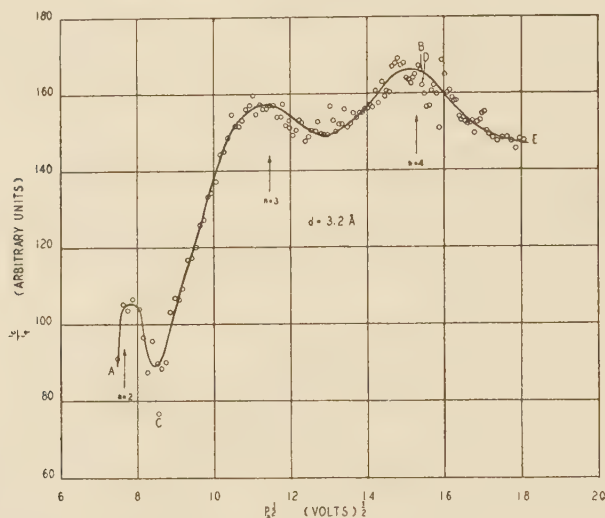


FIG. 6. Diffraction of electrons from oleic acid.  $\theta = 30^\circ$

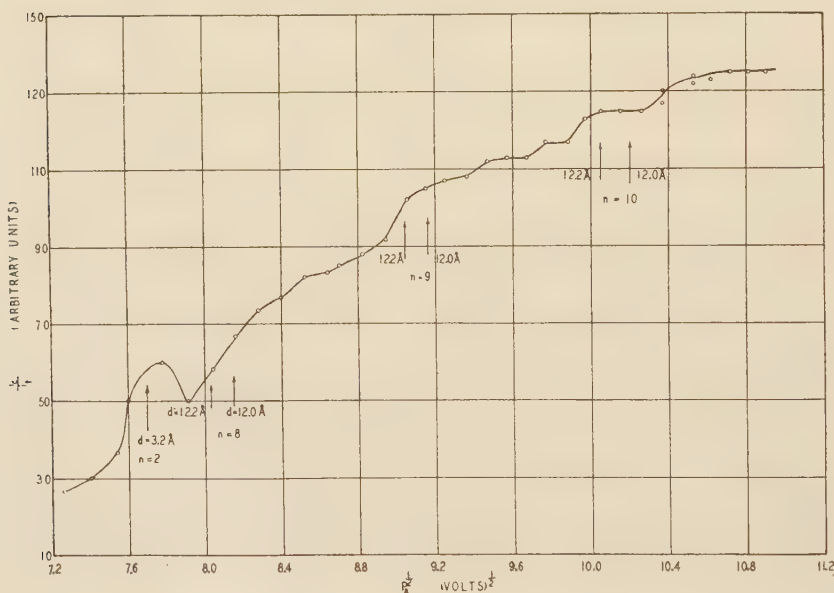


FIG. 7. Diffraction of electrons from repurified oleic acid.  $\theta = 30^\circ$

A portion of the sample of oleic acid used above was further purified by evaporation *in vacuo* at an even slower rate than previously. This proc-



ess removed a very small percentage of solid acids. An experiment (figure 7) was made on this sample for the region from  $P_a^{\frac{1}{2}} = 7$  volts $^{\frac{1}{2}}$  to  $P_a^{\frac{1}{2}} = 11$  volts $^{\frac{1}{2}}$ . The collector current was measured by taking the potential drop across a resistance of  $2.56 \times 10^{11}$  ohms by means of the electrometer. The thermionic current was kept at a fixed value by adjusting the filament current. A maximum, which corresponds to the second order for  $d = 3.2$  A.U., is quite pronounced. This experiment, as well as all the others on oleic acid, failed to show good evidence for the distance of 12.0 A.U. as reported by Buhl and Rupp (1). The positions for the maxima corresponding to the eighth, ninth, and tenth orders for a spacing of 12 A.U. are indicated in figure 7.

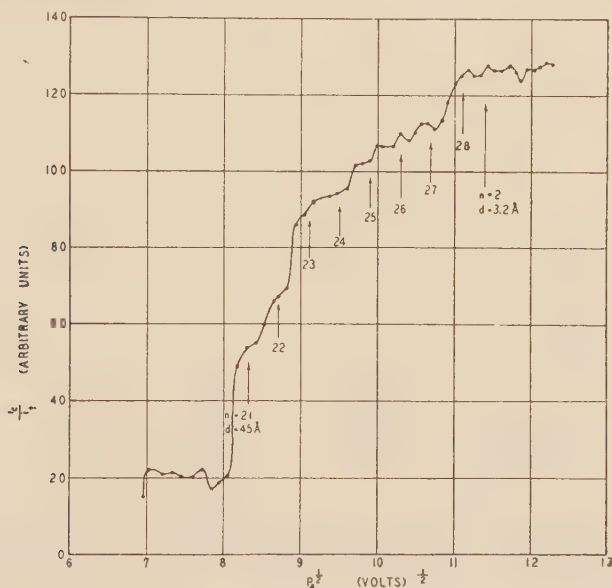


FIG. 8. Diffraction of electrons from oleic acid.  $\theta = 20^\circ$

*Experiment with a fixed angle of  $20^\circ$  (oleic acid).* The angle used in this experiment was such that the maxima for the 3.2 A.U. spacing were too broad ( $P_a^{\frac{1}{2}} = 5.7$  volts $^{\frac{1}{2}}$ ), and the maxima for the 45 A.U. spacing were of high orders. The second order for a spacing of 3.2 A.U. and the twenty-first to the twenty-eighth order for a spacing of 45 A.U. are indicated by arrows on the graph for comparison (figure 8).

*Diffraction of electrons from the (100) cleavage plane of a single crystal of sodium chloride*

Large single crystals of sodium chloride were cleaved in order to obtain a fresh surface. The size of the crystal thus prepared was about 5 mm. x 5 mm. x 3 mm. The crystal was put on the holder and placed in the



$\phi = 10$ ) would occur in the region from  $P_a^{\frac{1}{2}} = 13$  volts $^{\frac{1}{2}}$  to  $P_a^{\frac{1}{2}} = 16.2$  volts $^{\frac{1}{2}}$ . This might explain why there are no well-defined maxima in this region.

*Experiment 2, curve CD of figure 9 ( $\theta = 30^\circ$ ).* The filament was allowed to burn for two hours before any data were taken. A well-defined maximum occurs corresponding to the second order for  $n = 5/2$  and  $\phi = 10$ . This maximum exhibited a fluctuating intensity, though the average collector current was fairly constant. The encircled points on the curve are check points taken at the end of the experiment. The agreement is excellent.

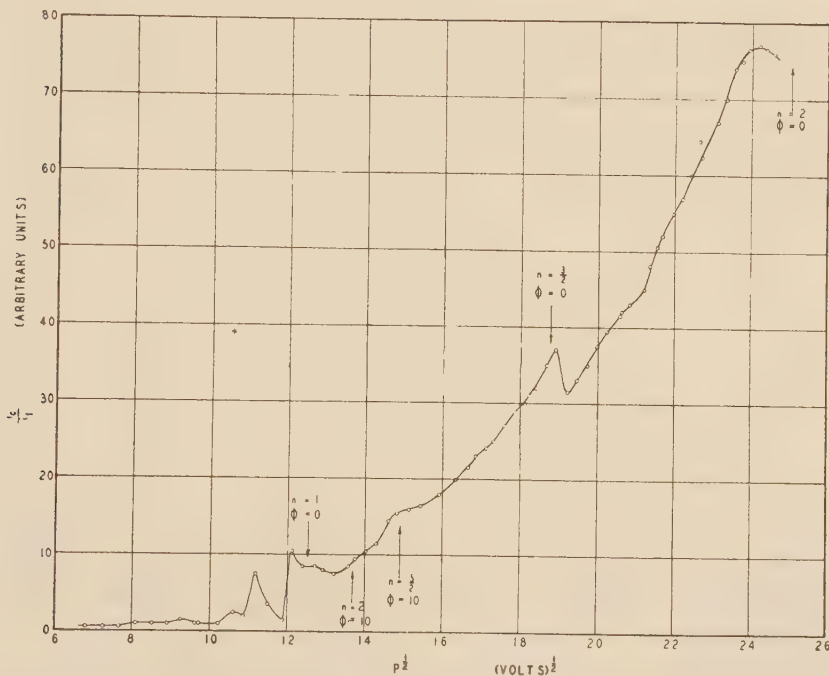


FIG. 10. Diffraction of electrons from the (100) cleavage plane of a single crystal of sodium chloride.  $\theta = 10^\circ$

*Experiment 3, curve EF of figure 9 ( $\theta = 30^\circ$ ).* The surface was bombarded for a period of ten seconds with 386-volt electrons. A period of fifty seconds was allowed to elapse before a reading which required sixty seconds to complete was taken. This curve shows fair agreement with curve CD. In addition to the maxima exhibited in curve CD, curve EF has two other rather weak peaks, which correspond to  $n = 3/2$  and  $\phi = 0$ , and  $n = 2$  and  $\phi = 0$ . Peaks corresponding to a lattice potential of zero are often weaker than the regular peaks for a great many substances.



The values  $d = 2.81$  A.U.,  $\theta = 30^\circ$ , and  $\phi = 10$  volts were substituted in equation 8, which yielded the condition for maxima

$$P^{\frac{1}{2}} = 4.34 (n^2 - 2.106)^{\frac{1}{2}}$$

$P^{\frac{1}{2}}$  for the maxima, which correspond to  $n = \frac{1}{2}$  and  $n = 1$ , has an imaginary value and the maxima should be absent.

*Experiment 4, sodium chloride, figure 10 ( $\theta = 10^\circ$ ).* A retarding potential equal to 6 volts less than the accelerating potential was applied between the apertures  $S_4$  and  $S_5$ . Electrons which had lost 6 volts or more of their original energy did not enter the Faraday chamber. The curve exhibits four maxima, three of which agree best with  $n = 1$ ,  $n = 3/2$ , and  $n = 2$  for  $\phi = 0$ . The calculated and observed maxima are given in table 2.

*The diffraction of electrons from the (100) cleavage plane of galena at 206°C.*

A large single crystal of natural galena was cleaved into a smaller crystal (3 mm. x 3 mm. x 2 mm.). The (100) plane thus obtained appeared

TABLE 2  
Calculated and observed values of  $P^{\frac{1}{2}}$

| $n$ | $P^{\frac{1}{2}}$<br>(CALCULATED) | $P^{\frac{1}{2}}$<br>(OBSERVED) |
|-----|-----------------------------------|---------------------------------|
|     |                                   | 11.2                            |
| 1   | 12.52                             | 12.1                            |
| 3/2 | 18.78                             | 18.9                            |
| 2   | 25.04                             | 24.2                            |

quite uniform to the eye by reflected light. Preliminary measurements on this crystal at room temperature failed to reveal any clearly defined peaks between 50 and 420 volts.<sup>5</sup> The furnaces used for degassing the apparatus were put in place and the entire apparatus was heated to 200°C. for seven days. At the end of that time the pressure in the apparatus was  $7.0 \times 10^{-6}$  mm. with the usual heating current passing through the filament. Nine maxima were found between 50 and 300 volts, with the angle of incidence equal to  $75^\circ$ . It was impossible to use retarding potential in this experiment, as the dielectric absorption current in the quartz insula-

<sup>5</sup> The previous experiments on sodium chloride gave maxima which were relatively weak in intensity. Laschkarew (Z. Physik **85**, 631 (1933)) and his coworkers found that a single crystal of graphite acted as an electron optical surface at room temperature. That is, the collector current exhibited no maxima or minima as the accelerating voltage was varied. However, upon heating the crystal for two hours at 200°C. and then making observations at that temperature, very intense maxima were found. They explained this as being due to the ability of the graphite to absorb gas at room temperature and inability to retain it at 200°C.

tion on the collector system required too long a time to reach equilibrium. The thermionic current was kept constant at 0.500 milliampere by adjusting the filament heating current with a variable carbon resistor. The electrometer leak was  $2.56 \times 10^{11}$  ohms, and the electrometer sensitivity was 250 divisions per volt.

TABLE 3  
*Experiments on galena with different cooling agents on the grease traps*

| DATE OF EXPERIMENT | CURVE IN FIGURE 9 | COOLING AGENT ON GREASE TRAPS     | COOLING AGENT ON OTHER TRAPS |
|--------------------|-------------------|-----------------------------------|------------------------------|
| August 7, 1935     | AB                | Crushed carbon dioxide in acetone | Liquid nitrogen              |
| August 10, 1935    | CD                | None                              | Liquid nitrogen              |
| August 11, 1935    | EF                | Liquid nitrogen                   | Liquid nitrogen              |

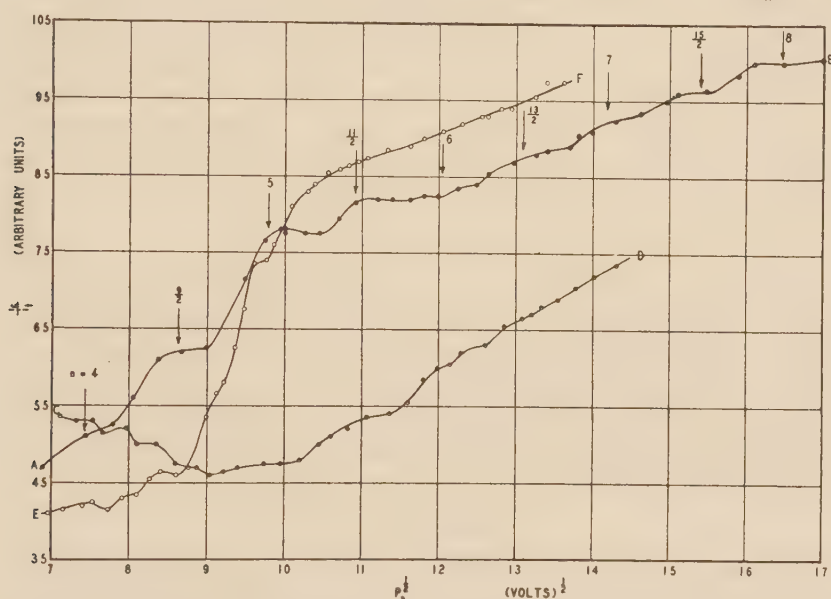


FIG. 11. Diffraction of electrons from the (100) cleavage plane of galena at  $206^{\circ}\text{C}$ .  
 $\theta = 75^{\circ}$ ;  $\Phi = 16.9$  volts

All of the following experiments on galena were performed with the entire diffraction apparatus at approximately  $206^{\circ}\text{C}$ . The experiments differed only in the cooling agent used on the traps, as shown in table 3.

The values  $d = 2.98$  A.U. and  $\theta = 75^{\circ}$ , when substituted in equation 8, yield the condition for maxima that  $0.222P = n^2 - 0.238\phi$ . The values of  $P$  for each maximum on curve AB of figure 11 were plotted against various values of  $n^2$ , and the series of points which fell on a straight line parallel to the line  $n^2 = 0.222P$  belonged to the correctly ordered maxima.

The difference between the experimental value of the voltage for a maximum and the value given by  $P = n^2/0.222$  is the inner potential for that maximum. The average value of the inner potential for the best defined maxima (maxima with  $n = 9/2, 5, 11/2, 13/2$ , and 7) was 16.9 volts.

An experiment (curve *CD*) without any cooling agent in the grease traps completely changed the shape of the curve, and very weak maxima, if any, could be found. An experiment twenty-four hours later with liquid nitrogen in the grease traps yielded a still different curve without well-defined peaks. The collector current was greater, owing, more than likely, to the better vacuum conditions. It seems reasonable to suppose that during the second experiment the organic vapors present were decomposed by the electron beam at the surface of the galena, thus forming a semi-amorphous layer which remained on the surface for at least twenty-four hours. Consequently, liquid nitrogen on the grease traps failed to bring out any maxima. A dark brown spot was easily seen on the surface of the galena where the electron beam had struck it; this was probably decomposed organic matter. The "fatigue effect" in the case of the oleic acid might be explained on the basis that the electron beam tended to decompose the oleic acid where it struck the surface of the oleic acid and the decomposition product diffused away slowly.

#### *Stearic acid*

A minute amount of stearic acid was placed upon a polished platinum plate, the temperature of which was just above the melting point of stearic acid. A thin visible film of stearic acid formed over the surface of the platinum and was quite homogeneous when cold. No maxima and minima were found, and the visible film of stearic acid disappeared. In all probability the film had evaporated in the high vacuum, and something less than a monomolecular film was left.

#### SUMMARY

Slow speed electrons were used to study various surfaces by means of electron diffraction. The angle of incidence was kept fixed and equal to the angle of reflection, while the accelerating voltage of the incident electron beam was varied. The collector current-accelerating voltage curve showed three broad distinct maxima with a surface of bulk liquid oleic acid, which corresponded to a distance of 3.2 A.U. A long distance of 45 A.U. was also found for oleic acid when the incident beam made a small angle with the surface of the liquid. Oleic acid showed a pronounced "fatigue effect," probably due to a growing surface charge. The (100) cleavage plane of sodium chloride gave maxima corresponding to an inner potential of zero and one of approximately 10 volts. Two methods of measuring were found which apparently did not show a fatigue effect.



The (100) cleavage plane of galena gave no well-defined maxima at room temperature. At 206°C. several well-defined maxima were found which corresponded to an inner potential of about 16.9 volts. Half-order, as well as whole-order peaks were found. Bombardment of the surface with slow speed electrons, at 206°C. and in the presence of a trace of organic vapor, permanently destroyed the grating properties of the galena surface. Stearic acid films on a polished platinum surface vaporized in the high vacuum before an experiment could be performed.

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